Applicability of Low-Floor Light Rail Vehicles in North America

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The state of the art in the development of low-floor light rail vehicles (LFLRVs) is investigated, and the applicability of LFLRVs for use in North America is assessed. LRV categories have been developed to facilitate understanding of the different types of vehicles and their applications. Forces driving the growing trend toward using low-floor vehicles are described, and an extensive compilation of data on LFLRVs and on North American LRT system characteristics is provided. An analytical perspective on the issues relevant to North American policy makers, managers, and engineers is presented, and sample applications are developed to demonstrate issues of cost-effectiveness, sources of risk, and trade-offs between use of low-floor and high-floor LRVs.

There is a growing trend toward the use of low-floor light rail vehicles (LFLRVs)—as of early 1994, more than 1,700 LFLRVs had been delivered to or ordered by transit system operators in Europe and North America. Since LFLRVs were introduced in Europe over 10 years ago, approximately 75 percent of new LRV orders in Europe have been for LFLRVs.

The same trend is now apparent in North America. Portland, the first North American city to adopt LFLRVs, will receive its new cars later this year. New-start projects including the Hudson Bergen LRT (New Jersey) and the Chicago Circulator have both embraced use of low-floor cars.

LFLRVs improve accessibility and are more easily integrated into the built environment than conventional LRVs. Low floors are typically 350 mm (13.8 in.) or less above the top of rail (TOR) compared with 910 mm (35.8 in.) or more for high floors. Only a single step is needed to board LFLRVs from curb level compared with three or four steps for conventional LRVs. Installing platforms, which might be something as simple as a raised curb, can provide level boarding of the LFLRV. In contrast, the platforms necessary to match high-floor vehicles extend high above the adjacent sidewalk.

Accessibility is becoming a much more important issue in North America. Transit agencies see the increasing need to provide barrier-free service. In the United States, the Americans with Disabilities Act of 1990 requires that rail transportation "be readily accessible to and usable by individuals with disabilities, including individuals who use wheelchairs."

There are problems with making conventional LRVs accessible. High platforms can be provided (mini or high platforms) to provide level boarding, but these take up considerable space and require a wider right of way. Carborne or wayside lifts can be used to raise wheelchairs from street level to the level of the car floor, but lifts are slow and not failproof. Whereas a person in a wheelchair can enter or exit a car during a normal station dwell time where level boarding is provided, it takes 2 to 4 min for this passenger to enter or to exit a vehicle when a lift is used. On systems with tight peak-period headways, one person in a wheelchair entering, then exiting, a car could cause delays so significant that a train could be lost from the peak-period schedule. Also, cars served by lifts or miniplatforms can usually accommodate only two wheelchairs per train. LFLRVs offer new solutions to these problems.

A remaining impediment to the adoption of LFLRVs was price. Recent data from North America and Europe indicate that the price difference between high-floor and low-floor LRVs has virtually disappeared and that an intelligently specified LFLRV can be procured for the same price as or less than a conventional high-floor car.

Accordingly, for all new-start projects, the most logical choice is a low-floor car. Only for systems requiring extensions or car replacements on systems with high platforms is the use of high-floor vehicles a serious option.

Classification of LFLRVs

A wide variety of LFLRVs are available, and many of them bear a great deal of similarity to each other. An extensive data base record of available vehicles is provided in Figure 1 and Table 1. Three categories have been developed to simplify discussion and understanding of LFLRVs:

1. Vehicles use conventional powered and trailing trucks. Vehicles are usually created by adding a body section, articulation, and an additional truck into a conventional LRV (Figure 2). The new body section contains the low-floor section (typically 9 to 15 percent of the floor area). The vehicles make extensive use of proven technology. Maintenance and operating costs are comparable to those for conventional high-floor vehicles.
2. Conventional motored trucks are used on Category 2 vehicles, so vehicle propulsion is not affected (Figure 3). To increase the amount of low-floor area in the vehicle (typically 50 to 70 percent of the floor area), modified trailer trucks are used. The trailing trucks might use smaller wheels, cranked axles, or independent wheels to accommodate the low-floor area above. The Portland vehicle is an example of a Category 2 vehicle. As do Category 1 vehicles, Category 2 vehicles make extensive use of proven technology. The modified trailer trucks have also proved to be very cost-effective and reliable, so vehicle operating and maintenance costs are comparable to those of conventional LRVs.
3. Innovative motored and trailing trucks and other novel technologies are used to create vehicles with a 100 percent low-floor area (Figure 4). Unlike conventional LRVs, standard modules are used to create vehicles with multiple articulations, and running gear and drive technologies are substantially different from those used on conventional vehicles. Designs vary widely, and the technology is still evolving rapidly. Category 3 vehicles have not been in service long enough to allow an assessment of long-term reliability, maintainability, or cost-effectiveness.

Comparison of Conventional and Low-Floor LRVs

The price of conventional LRVs ranges from $2 million to $2.2 million (1994 dollars) per car for orders of 30 or more cars on the basis of recent procurement information from San Francisco's Muni and Metro Dallas Area Rapid Transit. The premium cost for LFLRVs compared with a similar conventional vehicle is between 0 and 30 percent (Table 2). For the Portland Category 2 vehicle, the premium was approximately 10 percent. With the increasing number of low-floor vehicle orders, this premium is expected to disappear completely over the next 5 years.

Almost all experience with LFLRVs to date comes from Europe. European practices differ in some ways from those in North America, and the following issues warrant attention when adapting European vehicles:

- *Buff loads.* European LRVs are designed to withstand buff loads of 20 to 40 T, whereas North American vehicles are usually required to withstand loads equal to two times the car weight (Figure 5). The significant increase in longitudinal load-carrying capacity requires strengthening of European vehicles and will result in an increase to the vehicle's mass (Figure 6). In the case of mixed consist operation, particularly with conventional and Category 3 vehicles, this problem is exacerbated by the different floor heights of vehicles. The floor is one of the major structural components that must resist axial compression loads.
- *Coupling.* Category 1 and Category 2 vehicles use conventional power trucks, therefore coupling to conventional vehicles can be accommodated. Category 3 vehicles are often lengthened by adding a body section and articulation rather than by coupling to a second vehicle. Because of the different floor heights, coupling of Category 3 LFLRVs with Category 1 or 2 LFLRVs or other low- or high-floor vehicles would be problematic.
- *Operating speed.* Many European LFLRVs have top speeds of 70 km/hr (44 mph), which is substantially lower than some North American transit systems. With operation in city streets and close station spacing, common in Europe, higher top speeds are unimportant. Pro-

pulsion systems can be enhanced to provide vehicles that meet North American criteria.

- *Maintenance facilities.* With the reduced availability of space under the car to support equipment, LFLRVs use space above the roof of the car. As a result, less work is performed in pits, and more work is performed at the car roof level. Raised platforms are needed to support these efforts. Many LFLRVs are longer and have more body sections than conventional LRVs, too. Requirements for jacks, cranes, and pit and paint booth lengths may vary from those for existing fleets.
- *Fire resistance.* To reduce vehicle weights and improve energy consumption, European vehicles often use lightweight materials. Fire resistance of the car body and fire hardening of vehicle roofs are issues that need to be considered.

LFLRVs in the North American Context

There is a great deal of variety in the fleets operated by North American transit agencies and the accompanying right-of-way, systems, and station infrastructure. Depending on whether the agency is procuring vehicles, improving the accessibility of an existing line, building a line extension, or constructing a brand new line, the key issues to be addressed by the agency will vary. An

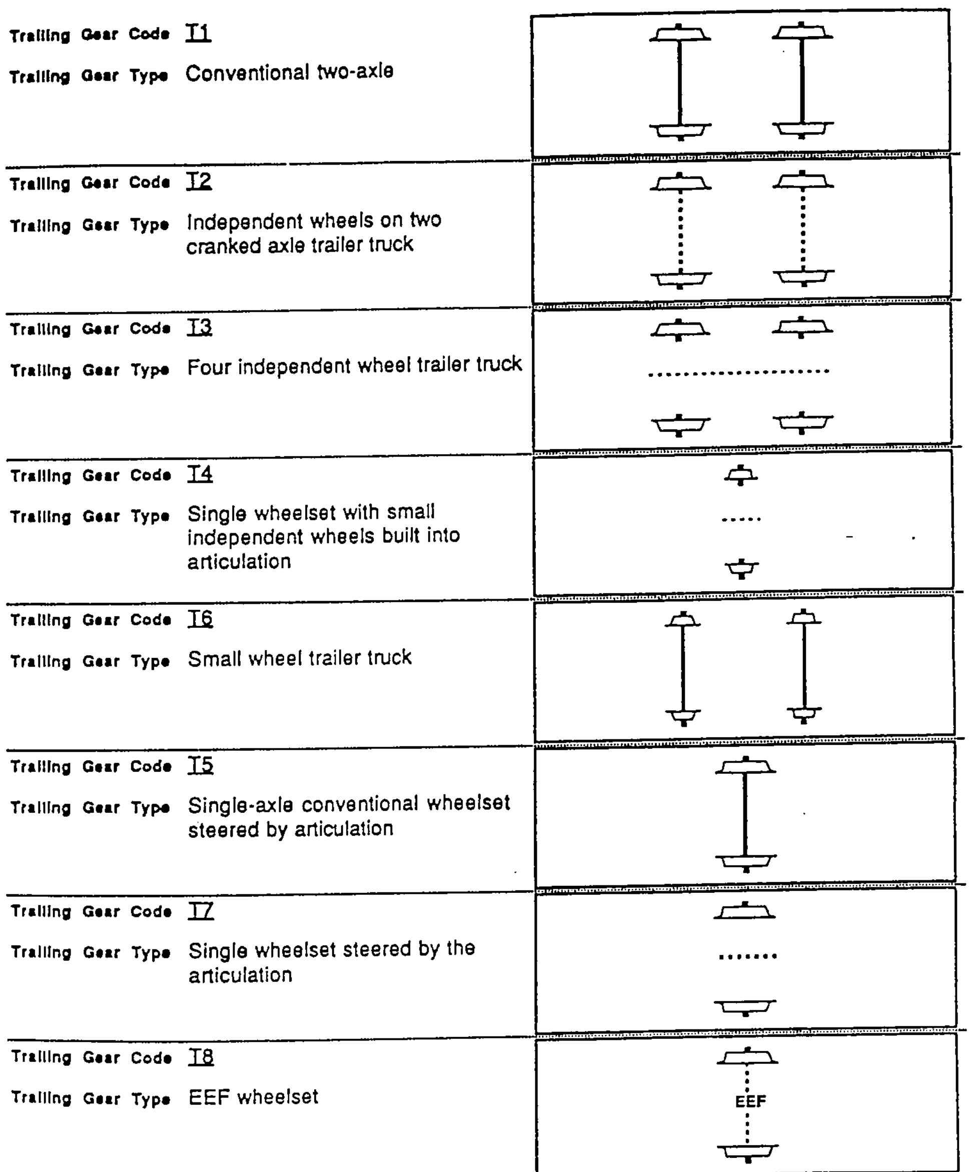
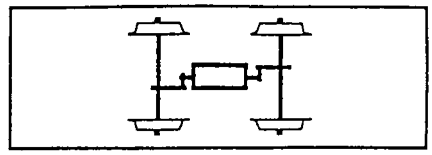


FIGURE 1 Conventional and LFLRV wheelset and drive arrangements.

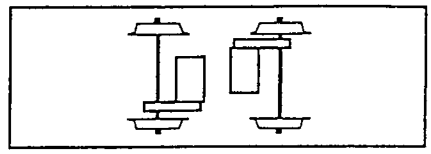
Power Gear Code M1

Power Gear Type Conventional monomotor



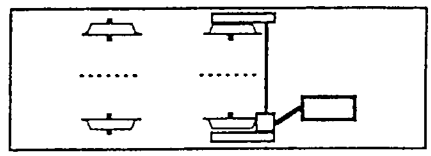
Power Gear Code M2

Power Gear Type Conventional bi-motor



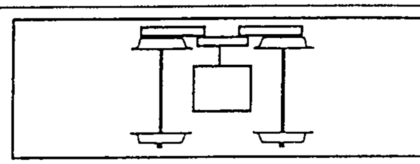
Power Gear Code M3

Power Gear Type Independent wheels, one pair driven, one pair free-wheeling



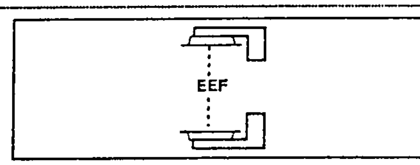
Power Gear Code M4

Power Gear Type Transverse-mounted motor drives both axles through parallel gears and cardan shaft



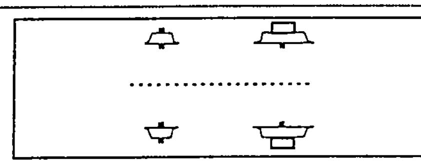
Power Gear Code M5

Power Gear Type Motored EEF self-steering wheelset



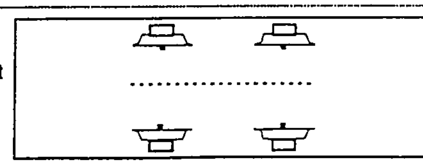
Power Gear Code M6

Power Gear Type Articulated truck frame, two large hub motor-driven wheels, two small guiding wheels



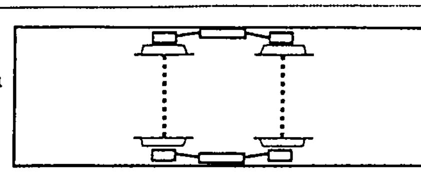
Power Gear Code M7

Power Gear Type Four hub motor-driven, independent wheels



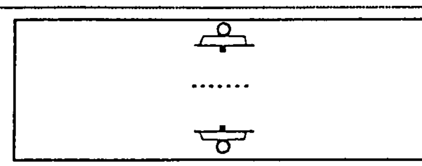
Power Gear Code M8

Power Gear Type Motor drives wheels on one side via cardan shafts



Power Gear Code M9

Power Gear Type Vertically mounted motors driving independent wheels built into articulation portal



Power Gear Code M10

Power Gear Type Independent wheels mounted on radial-arm axleboxes driven by motor via parallel gears

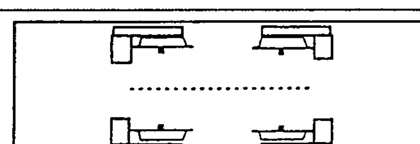


FIGURE 1 *Continued*

TABLE 1 Summary of Category 1, 2, and 3 LFLRVs

Category 1 Low Floor LRV's

City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m *ft*)	Car Width (m *ft*)	Floor Height Max (mm *in*)	Floor Height Min (mm *in*)	Weight (tonne *lbs*)	Max Speed (km/h *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Mannheim	Duewag		B'2'2'B'	23	9%	25.7 *84.2*	2.2 *7.2*	889 *35*	353 *13.9*	26 *57,320*	60 *37*	25 *82*	M1	T1	1991
Amsterdam/ GVBA	Bombardier (BN)	11G & 12G	Bo'Bo'Bo'Bo'	45	9%	25.6 *84.1*	2.4 *7.7*	870 *34.3*	280 *11*	36.9 *81,351*	70 *44*	25 *82*	M2		1989
Freiburg/ VAG	Duewag	GT 8C	B'B'B'B'	11	9%	32.8 *107.7*	2.3 *7.5*	910 *35.8*	270 *10.6*	38.5 *84,878*	70 *44*	25 *82*	M1		1990
Numberg	AEG (MAN)	N82	B'2'2'B'	12	9%	26.1 *85.6*	2.3 *7.5*	880 *34.6*	284 *11.2*	32.8 *72,312*	70 *44*	25 *82*	M1	T1	1992
Wurzburg	LHB	GT 8/8C	B'B'B'B'	14	10%	32.6 *107*	2.4 *7.9*	910 *35.8*	310 *12.2*	42.5 *93,697*	70 *44*	25 *82*	M1		1989
Antwerp/ De Lijn	Bombardier (BN)		B'2'2'B'	10	10%	29.3 *96.1*	2.3 *7.5*	860 *33.9*	350 *13.8*	42 *92,594*	80 *50*		M1	T1	1993
Basle/ BVB	Schindler (SIG)	Be 4/4	B'2'2'B'	19	15%	25.4 *83.3*	2.2 *7.2*	855 *33.7*	325 *12.8*	31 *68,343*	65 *40*	12 *39.4*	M1	T1	1987
Nantes/ SEMITAN	GEC Alsthom		B'2'2'B'	34	16%	39.2 *128.4*	2.3 *7.5*	873 *34.4*	353 *13.9*	51.9 *114,420*	70 *44*	25 *82*	M1	T1	1992
Nantes/ SEMITAN	GEC Alsthom		B'2'2'B'	12	18%	39.2 *128.4*	2.3 *7.5*	850 *33.5*	350 *13.8*	51.6 *113,759*	70 *44*		M1	T1	1993
Sheffield/ SYST	Duewag	GT 8	B'B'B'B'	25	34%	34.8 *114*	2.7 *8.7*	880 *34.6*	480 *18.9*	46 *101,413*	80 *50*	25 *82*	M1		1993
Freiburg	Duewag	GT8D-MNZ	Bo'Bo'Bo'Bo'	26	48%	33.1 *108.6*	2.3 *7.5*	560 *22*	290 *11.4*	38.5 *84,878*	70 *44*	19 *62.3*	M2		1993
RBS	Schindler (SIG)	ABe4/8	Bo'2'2'Bo'	23	50%	39.3 *128.9*	2.7 *8.7*	830 *32.7*	390 *15.4*	51 *112,436*	90 *56*		M2	T1	1992

Sum of Category 1 Cars Ordered 254

Category 2 Low Floor LRV's

City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m *ft*)	Car Width (m *ft*)	Floor Height Max (mm *in*)	Floor Height Min (mm *in*)	Weight (tonne *lbs*)	Max Speed (km/h *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Trailing Gear: Independent wheels on two cranked axle trailer truck															
Portland	Duewag		Bo'2Bo'	46	66%	28.0 *92*	2.7 *8.7*	980 *38.6*	355 *14*	44 *97,003*	88 *55*	25 *82*	M2	T2	1995
Grenoble/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	38	65%	29.4 *96.5*	2.3 *7.5*	875 *34.4*	345 *13.6*	43.9 *96,783*	70 *44*	25 *82*	M1	T2	1987
Grenoble/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	7	65%	29.4 *96.5*	2.3 *7.5*	875 *34.4*	345 *13.6*	43.9 *96,783*	70 *44*	25 *82*	M2	T2	1995
Paris/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	17	65%	29.4 *96.5*	2.3 *7.5*	875 *34.4*	345 *13.6*	43.9 *96,783*	70 *44*	25 *82*	M1	T2	>1993
Rouen/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	28	65%	29.4 *96.5*	2.3 *7.5*	875 *34.4*	345 *13.6*	43.9 *96,783*	70 *44*	25 *82*	M1	T2	1993
Val de Seine/ SEMITAG	GEC Alsthom	ZR 2000	B'2'B'	17	65%	29.4 *96.5*	2.3 *7.5*	875 *34.4*	345 *13.6*	43.9 *96,783*	70 *44*	25 *82*	M1	T2	>1993
Trailing Gear: Four independent wheel trailer truck															
Buenos Aires	Duewag		Bo'2Bo'	9	62%	23.8 *78*	2.4 *7.9*	560 *22*	350 *13.8*	29.7 *65,477*	70 *44*	25 *82*	M2	T3	1994
Valencia	Duewag		Bo'2Bo'	24	62%	23.8 *78*	2.4 *7.9*	560 *22*	350 *13.8*	29.7 *65,477*	65 *40*	20 *65.6*	M2	T3	1994
Turin/ ATM	Fiat (Firema)	5000	B'2'B	54	56%	22.2 *72.8*	2.3 *7.5*	870 *34.3*	350 *13.8*	30 *66,139*	60 *37*	16 *52.5*	M1	T3	1989
Dresden	Duewag	6MGT	Bo'22Bo'	20	64%	40.5 *132.9*	2.4 *7.9*	600 *23.6*	350 *13.8*	42 *92,594*	70 *44*	15 *49.2*	M2	T3	>1993
Mannheim	Duewag	6MGT	Bo'2Bo'	64	64%	29.9 *98.1*	2.4 *7.9*	600 *23.6*	350 *13.8*	33 *72,753*	70 *44*	15 *49.2*	M2	T3	1994
Mannheim	Duewag	6MGT	Bo'22Bo'	5	64%	40.5 *132.9*	2.4 *7.9*	600 *23.6*	350 *13.8*	42 *92,594*	70 *44*	15 *49.2*	M2	T3	1994
Mannheim	ABB Henschel	6NGT/ Variotram	N/A	2	70%	0.0 *0*	0.0 *0*	N/A *0*	290 *11.4*	N/A *0*	N/A *0*	N/A *0*	M2	T3	1996
Karlsruhe	Duewag	70D/N	Bo'2Bo'	20	61%	28.8 *94.6*	2.7 *8.7*	580 *22.8*	390 *15.4*	34.5 *76,060*	80 *50*		M2	T3	1994
Brno City Transport	CKD Tatra	RT6-N1	Bo'2Bo'	12	63%	26.3 *86.2*	2.4 *8*	900 *35.4*	350 *13.8*	32 *70,548*	80 *50*	25 *82*	M2	T3	>1993
Prototype	CKD Tatra	RT6-N1	Bo'2Bo'	1	63%	26.3 *86.2*	2.4 *8*	900 *35.4*	350 *13.8*	32 *70,548*	80 *50*	25 *82*	M2	T3	1993
Rome/ ATAC	Socimi	T8000	Bo'2Bo'	34	54%	21.2 *69.6*	2.3 *7.5*	835 *32.9*	350 *13.8*	29.7 *65,477*	70 *44*	15 *49.2*	M2	T3	1990
Trailing Gear: Single-axle conventional wheelset steered by articulation															
Cologne	Bombardier (Rotax)	T	Bo'1'1'Bo'	40	60%	26.8 *87.9*	2.7 *8.7*	530 *20.9*	440 *17.3*	34.7 *76,500*	80 *50*	20 *65.6*	M2	T5	>1993
Vienna U-Bahn	Bombardier (Rotax)	T	Bo'1'1'Bo'	68	60%	26.8 *87.9*	2.7 *8.7*	530 *20.9*	440 *17.3*	34.7 *76,500*	80 *50*	20 *65.6*	M2	T5	1992

TABLE 1 (*Continued*)

Category 2 Low Floor LRV's

City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m *ft*)	Car Width (m *ft*)	Floor Height Max (mm *in*)	Floor Height Min (mm *in*)	Weight (tonne *lbs*)	Max Speed (km/h *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Trailing Gear: Small wheel trailer truck															
Leipzig	Duewag	8NGT	Bo'2'2'Bo'	25	61%	27.8 *91.2*	2.2 *7.2*	560 *22*	300 *11.8*	32 *70,548*	70 *44*		M2	T6	1994
Swiss-Italian Railway/ FART	ACM Vevey	ABe4/6	Bo'2'Bo'	12	60%	30.3 *99.4*	2.7 *8.7*	900 *35.4*	530 *20.9*	42.5 *93,697*	80 *50*		M2	T6	1992
Geneva/ TPG	ACM Vevey	Be4/6	B'2'B'	46	60%	21.0 *68.9*	2.3 *7.5*	870 *34.3*	480 *18.9*	27 *59,525*	60 *37*	17.5 *57.4*	M1	T6	1984
St. Etienne/ STAS	GEC Alsthom	Be4/6	B'2'B'	25	59%	23.2 *76.2*	2.1 *6.9*	710 *28*	350 *13.8*	27.4 *60,407*	70 *44*	18 *59.1*	M1	T6	1991
Bern/ SVB	ACM Vevey	Be4/8	B'2'2'B'	12	73%	31.0 *101.7*	2.2 *7.2*	710 *28*	350 *13.8*	34 *74,957*	60 *37*	15 *49.2*	M1	T6	1989
Geneva	ACM Vevey	Be4/8 Intermediate	N/A	18	0%	0.0 *0*	0.0 *0*	N/A *0*	350 *13.8*	N/A *0*	N/A *0*	N/A *0*	M1	T6	1995
Magdeburg	LHB	NGT 8D	Bo'2'2'Bo'	120	60%	29.0 *95.1*	2.3 *7.5*	570 *22.4*	350 *13.8*	34 *74,957*	70 *44*		M2	T6	1995
Trailing Gear: EEF wheelset															
Rostock	Duewag	6NGTWDE	Bo'1'1'Bo'	50	50%	30.4 *99.7*	2.3 *7.5*	560 *22*	350 *13.8*	30.4 *67,021*	70 *44*	15 *49.2*	M2	T8	1994
Bogestra/ Bochum	Duewag	MGT6D	Bo'1'1'Bo'	43	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	1992
Brandenburg	Duewag	MGT6D	Bo'1'1'Bo'	4	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	>1993
Erfurt	Duewag	MGT6D	Bo'1'1'Bo'	4	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	>1993
Halle	Duewag	MGT6D	Bo'1'1'Bo'	14	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	1992
Heidelberg	Duewag	MGT6D	Bo'1'1'Bo'	12	63%	28.9 *94.9*	2.3 *7.5*	540 *21.3*	350 *13.8*	31.5 *69,446*	70 *44*	15 *49.2*	M2	T8	1994
Mulheim	Duewag	MGT6D	Bo'1'1'Bo'	4	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	32 *70,548*	70 *44*	15 *49.2*	M2	T8	>1993
Kassel/ KVG	Duewag	NGT6C	B'1'1'B'	25	70%	28.8 *94.3*	2.3 *7.5*	700 *27.6*	350 *13.8*	30.2 *66,580*	70 *44*	15 *49.2*	M1	T8	1990
Bonn	Duewag	NGT6D	Bo'1'1'Bo'	24	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	31.5 *69,446*	70 *44*	15 *49.2*	M2	T8	1994
Dusseldorf	Duewag	NGT6D	Bo'1'1'Bo'	10	65%	28.6 *93.9*	2.3 *7.5*	560 *22*	350 *13.8*	31.5 *69,446*	70 *44*	15 *49.2*	M2	T8	>1993

Sum of Category 2 Cars Ordered 954

Category 3 Low Floor LRV's

City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m *ft*)	Car Width (m *ft*)	Floor Height Max (mm *in*)	Floor Height Min (mm *in*)	Weight (tonne *lbs*)	Max Speed (km/h *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Power Gear: Unknown															
Prototype (Turin)	Firema	Prototype	Bo'2'Bo'	1	100%	22.2 *72.8*	2.3 *7.5*	350 *13.8*	350 *13.8*	24 *52,911*	90 *56*			T3	
Power Gear: Independent wheels mounted on radial-arm axleboxes driven by motor via parallel gears															
Prototype (Rome)	Socimi		BoBoBo	1	100%	22.0 *72.2*	2.4 *7.9*	350 *13.8*	350 *13.8*	25 *55,116*	60 *37*		M10		1992
Strasbourg	ABB (Socimi)	Eurotram	BoBoBo2	26	100%	32.5 *106.6*	2.4 *7.9*	350 *13.8*	350 *13.8*	29 *63,934*	60 *37*	25 *82*	M10	T3	1994
Prototype (Milan)	Socimi	S-350LRV	Bo'Bo'	1	100%	14.0 *45.9*	2.4 *7.9*	350 *13.8*	350 *13.8*	10.5 *23,149*	70 *44*	15 *49.2*	M10		1989
Power Gear: Independent wheels, one pair driven, one pair free-wheeling															
Augsburg	AEG (MAN)	GT6M	1A'A1'A1'	1	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	29.6 *65,257*	70 *44*	15 *49.2*	M3		1993
Berlin	AEG (MAN)	GT6N	1A'A1'A1'	120	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		1994
Braunschweig	AEG (MAN)	GT6N	1A'A1'A1'	11	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		>1993
Bremen	AEG (MAN)	GT6N	1A'A1'A1'	18	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		1990
Frankfurt-an-der-Oder	AEG (MAN)	GT6N	1A'A1'A1'	13	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		>1993
Halle	AEG (MAN)	GT6N	1A'A1'A1'	1	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		>1993
Munich	AEG (MAN)	GT6N	1A'A1'A1'	70	100%	27.3 *89.6*	2.3 *7.5*	350 *13.8*	300 *11.8*	29.4 *64,816*	70 *44*	15 *49.2*	M3		1994
Zwickau	AEG (MAN)	GT6N	1A'A1'A1'	12	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	26.8 *59,084*	70 *44*	15 *49.2*	M3		>1993
Munich	AEG (MAN)	GT6N/ R1.1	1A'A1'A1'	3	100%	26.5 *86.9*	2.3 *7.5*	350 *13.8*	300 *11.8*	29.5 *65,036*	70 *44*	15 *49.2*	M3		1990
Bremen	AEG (MAN)	GT8N	1A'1A'1A'1A'	61	100%	35.0 *114.8*	2.3 *7.5*	350 *13.8*	300 *11.8*	34 *74,957*	70 *44*	15 *49.2*	M3		1993
Jena	AEG (MAN)	GT8N	1A'1A'1A'1A'	10	100%	35.0 *114.8*	2.3 *7.5*	350 *13.8*	300 *11.8*	34 *74,957*	70 *44*	15 *49.2*	M3		>1993
Power Gear: Transverse-mounted motor drives both axles through parallel gears and cardan shaft															
Lille	Breda	VLC	B'1 1 1 B'	24	80%	29.9 *98.1*	2.4 *7.9*	950 *37.4*	350 *13.8*	40 *88,185*	70 *44*	25 *82*	M4	T4	1993
Prototype (Rome)	Breda	VLC	B'1 1 B'	1	75%	22.0 *72.2*	2.5 *8.2*	950 *37.4*	350 *13.8*	22 *48,502*	70 *44*	20 *65.6*	M4	T4	1990

(*continued on next page*)

TABLE 1 (*Continued*)

Category 3 Low Floor LRV's

City	Builder	Type	Axle Arrangement	Number of Cars	% Low Floor	Car Length (m *ft*)	Car Width (m *ft*)	Floor Height Max (mm *in*)	Floor Height Min (mm *in*)	Weight (tonne *lbs*)	Max Speed (km/h *mph*)	Min Curve Radius (m, *ft*)	Running Gear Type Power	Running Gear Type Trailer	First Car
Power Gear: Motored EEF self-steering wheelset															
Mannheim/ MVG	German Consortium	dGTW-ER	A'A'A'1'	1	100%	26.7 *87.6*	2.3 *7.5*	350 *13.8*	290 *11.4*	23.98 *52,867*	70 *44*	15 *49.2*	M5	T8	1991
Dusseldorf/ RBG	German Consortium	GTW-ER	A'A'1'	1	100%	20.2 *66.2*	2.4 *7.9*	350 *13.8*	290 *11.4*	17.75 *39,132*	70 *44*	18 *59.1*	M5	T8	1991
Bonn/SWB	German Consortium	GTW-ZR	A'A'1'	1	100%	20.2 *66.2*	2.4 *7.9*	350 *13.8*	290 *11.4*	18.56 *40,918*	70 *44*	18 *59.1*	M5	T8	1991
Power Gear: Articulated truck frame, two large hub motor-driven wheels, two small guiding wheels															
Prototype	Bombardier (BN)	LRV2000	A'1'1'A'1'A'	1	100%	20.2 *66.3*	2.5 *8.1*	350 *13.8*	350 *13.8*	24 *52,911*	70 *44*		M6		1990
Brussels	Bombardier (BN)	TRAM2000	A'1'Bo1'A'	51	100%	22.8 *74.8*	2.3 *7.5*	350 *13.8*	350 *13.8*	31.9 *70,328*	70 *44*	17.5 *57.4*	M6		1994
Power Gear: Four hub motor-driven, independent wheels															
Chemnitz	ABB Henschel	6NGT/ Variotram	Bo'2'Bo'	53	100%	30.9 *101.4*	2.7 *8.7*	350 *13.8*	290 *11.4*	28.3 *62,391*	70 *44*	18 *59.1*	M7	T3	1993
Wurzburg	LHB	GTW	Bo'Bo'Bo'	20	100%	29.1 *95.5*	2.4 *7.9*	350 *13.8*	300 *11.8*	35 *77,162*	80 *50*		M7		>1993
Frankfurt am Main	Duewag	R3.1	Bo'2'Bo'	20	100%	27.2 *89.2*	2.4 *7.7*	350 *13.8*	300 *11.8*	33 *72,753*	70 *44*	18 *59.1*	M7	T3	1993
Power Gear: Motor drives wheels on one side via cardan shafts															
Prototype	Schindler (SIG)	Cobra 370	A'A'A'A'	1	100%	24.5 *80.4*	2.3 *7.5*	370 *14.6*	320 *12.6*	25 *55,116*	65 *40*	11.8 *38.7*	M8		1993
Power Gear: Vertically mounted motors driving independent wheels built into articulation portal															
Vienna "A"	SGP	ULF197-4	1A'A'A'1	100*	100%	23.6 *77.5*	2.4 *7.9*	197 *7.8*	197 *7.8*	23 *50,706*	70 *44*	18 *59.1*	M9	T7	1995
Vienna "A" Prototype	SGP	ULF197-4	1'A'A'A'1	1	100%	23.6 *77.5*	2.4 *7.9*	197 *7.8*	197 *7.8*	23 *50,706*	70 *44*	18 *59.1*	M9	T7	1994
Vienna "B"	SGP	ULF197-6	1'A'A'A'A'1'	50*	100%	34.9 *114.4*	2.4 *7.9*	197 *7.8*	197 *7.8*	32.5 *71,650*	70 *44*	18 *59.1*	M9	T7	1995
Vienna "B" Prototype	SGP	ULF197-6	1'A'A'A'A'1	1	100%	34.9 *114.4*	2.4 *7.9*	197 *7.8*	197 *7.8*	32.5 *71,650*	70 *44*	18 *59.1*	M9	T7	1994

Sum of Category 3 Cars Ordered 675

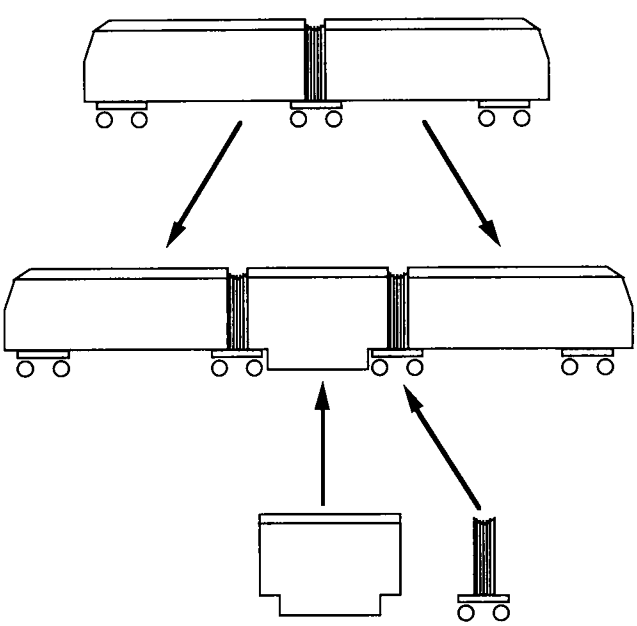


FIGURE 2 LFLRV achieved by converting conventional six-axle, single-articulation LRV into eight-axle, double-articulation LRV.

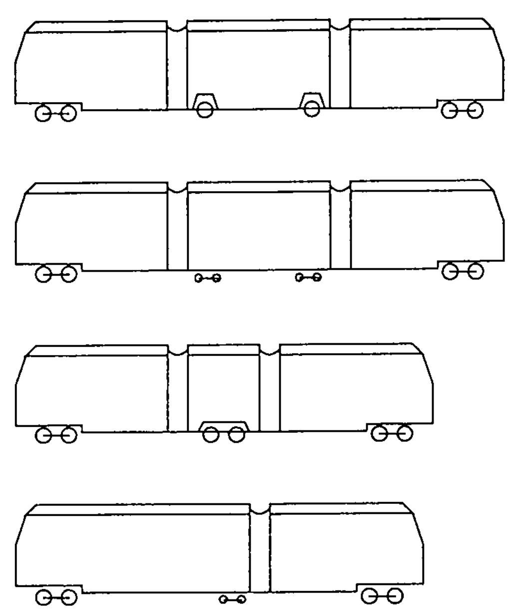


FIGURE 3 Various configurations of Category 2 LFLRVs with conventional motor trucks (not to scale).

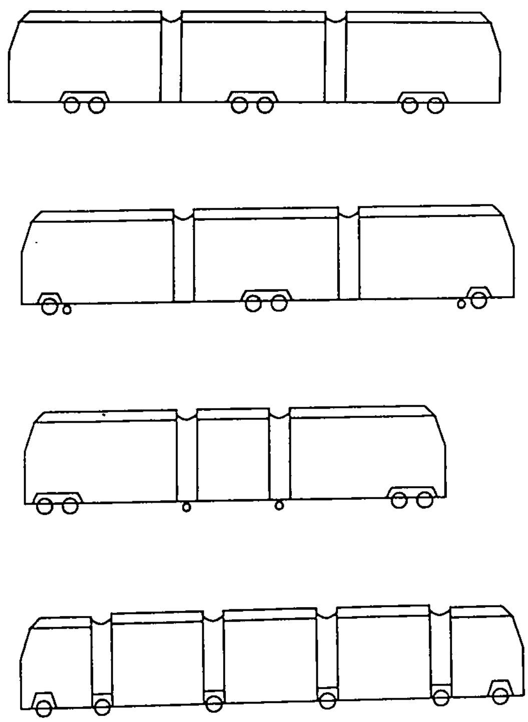


FIGURE 4 Typical configurations of Category 3 LFLRVs (not to scale).

applicability assessment strategy that can be used to evaluate the effectiveness of low-floor vehicles is described here and shown in Figure 7:

- *Define options.* The availability of LFLRV solutions provides a new range of options. They include mixed consist operation (conventional LRVs and LFLRVs) and the construction of low platforms to allow level boarding at the low-floor level. Other options relating to LFLRVs are similar to high-floor options.
- *Assess technological risk.* Category 1 and Category 2 LFLRVs use technology with a history of reliability and performance, but Category 3 LFLRVs incorporate many technological innovations never tried before. Agencies should select a vehicle consistent with the degree of risk that they are willing to accept.
- *Evaluate physical compatibility.* The compatibility of LFLRVs with the existing infrastructure must be assessed. If a new system is being constructed, the physical infrastructure and the vehicles can be designed to complement each other. If it is an existing system, the ability of cars to run in mixed consists and the potential need for retrofits of platforms, shops, right of way, and systems must be considered. Where the existing line has a number of existing high platforms to provide level boarding of conventional LRVs, using LFLRVs is most likely inappropriate.
- *Quantify operational impacts.* The operation and maintenance of a mixed fleet complicate work practices.

TABLE 2 Category 2 Vehicle Prices

CITY	BUILDER	LENGTH	WIDTH	YEAR OF DELIVERY	NUMBER OF VEHICLES	US $ EQUIVALENT
Paris[1]	GEC-Alsthom	29.4 m (96 ft 5.5 in)	2.3 m (7 ft 6 in)	1991	34	2,400,000
Geneva[1]	ACM Vevey	21.0 m (68 ft 11 in)	2.3 m (7 ft 6 in)	1990	46	2,350,000
Portland (Tri-Met)[1]	Siemens-Duewag Corp.	28.0 m (92 ft)	2.65 m (8 ft 8 in)	1995	46	2,319,000
Grenoble[2]	GEC-Alsthom	29.4 m (96 ft 5.5 in)	2.3 m (7 ft 6 in)	1987	38	2,363,000
Mannheim[2]	Duewag	29.9 m (98 ft 1 in)	2.4 m (7 ft 11 in)	1994	64	2,010,000
Dusseldorf[2]	Duewag	28.6 m (93 ft 8 in)	2.3 m (7 ft 6 in)	–	10	1,635,000
Boston[2]	Breda	22.68 m (75 ft)	2.64 m (8 ft 8 in)	1999	100	2,100,000

1 Information obtained through interviews
2 Information obtained from *Railway Gazette International Year Book,* Developing Metros 1994, "German Cities Dominate Deliveries of Novel Low and Middle-Floor Cars."

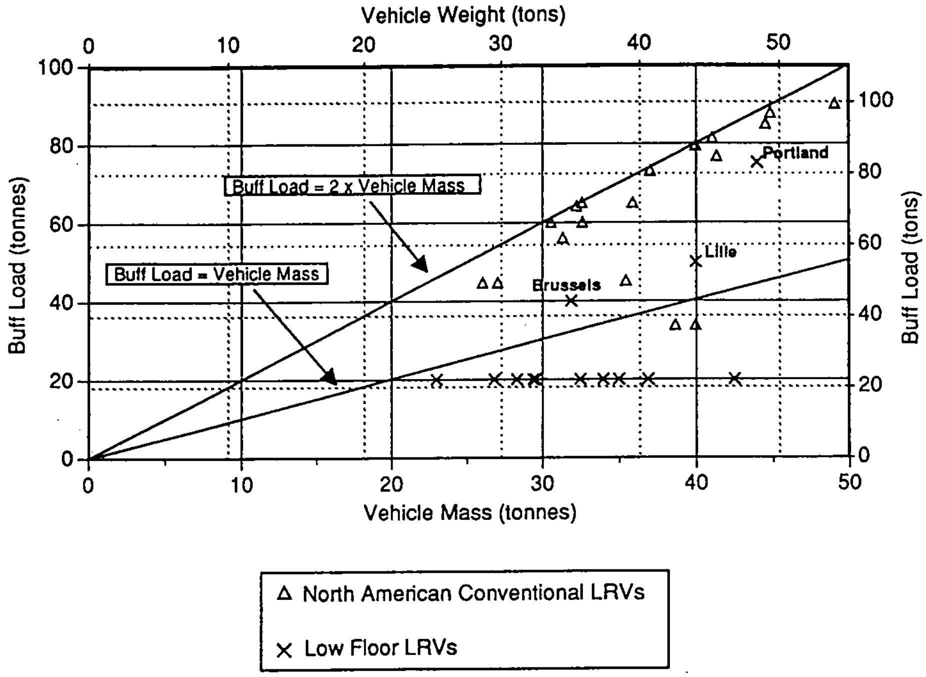


FIGURE 5 Comparison of buff load.

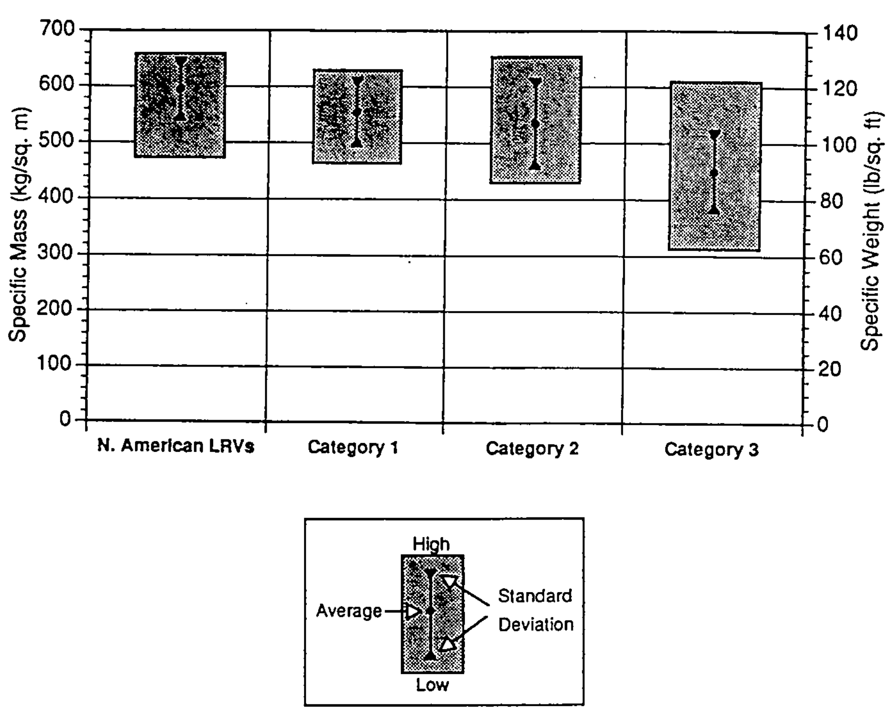


FIGURE 6 Comparison of specific mass for LFLRVs and conventional North American LRVs.

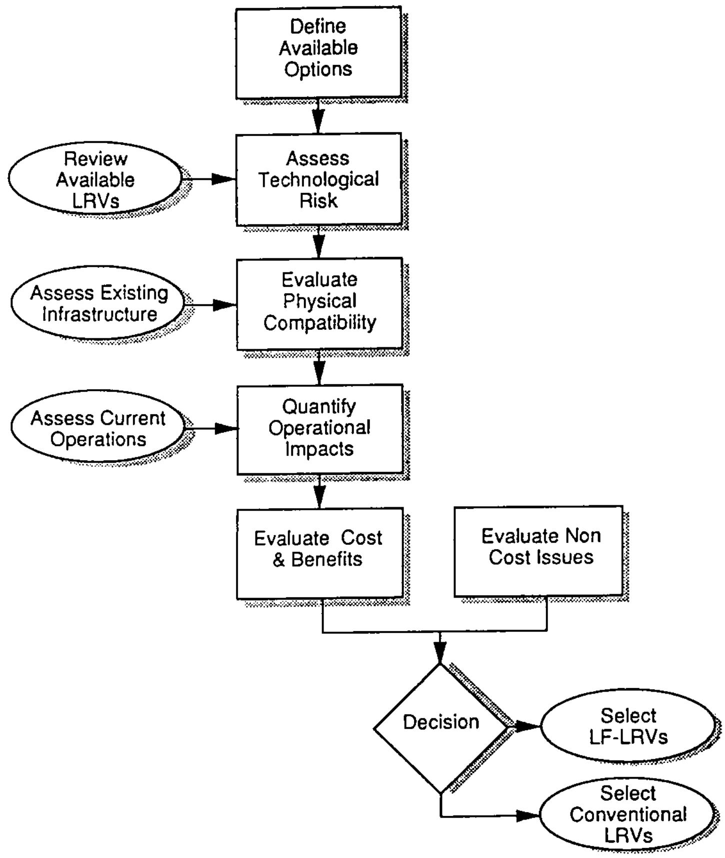


FIGURE 7 Applicability assessment model.

At the same time, LFLRVs offer many advantages. Improved accessibility is an important consideration. If level boarding of LFLRVs can be provided where level boarding of conventional LRVs cannot, a significant improvement in service reliability and reduction in round-trip time are possible. Reduced round-trip times may allow decreases in fleet requirements. For example, with wayside lift loading and unloading of two passengers, a system delay of 10 min or more is possible. Delays of 10 min per trip will manifest either as reduced service reliability or increased vehicle requirements to compensate for the delays. With 10-min headways, one additional train would be required. Level boarding of LFLRVs effectively removes boarding delays and the need for additional vehicles.

- *Evaluate costs and benefits.* LFLRVs currently cost up to 10 percent more than similar conventional vehicles. It is anticipated that the cost premium for LFLRVs will soon disappear. In addition, loading platforms can be constructed much more cheaply for LFLRVs, and operating efficiencies may result in fleet requirement savings.
- *Evaluate noncost issues.* Transit agencies should weigh a number of noncost considerations. The public increasingly expects barrier-free accessibility to public transportation. The degree of visibility and intrusion of system infrastructure into the built environment around an LRT line are directly affected by the type of vehicle used. LFLRVs provide superior solutions with respect to both concerns.

Summary

The Americans with Disabilities Act has been a great catalyst in the United States in the movement toward LFLRV solutions. Portland and more recently Boston have demonstrated that LFLRVs can be implemented in North America in a very cost-effective fashion.

As more LFLRV systems are installed, the premium cost of low-floor versus high-floor vehicles will continue to fall; it is expected that the gap in prices will disappear very soon. LFLRVs will become the norm for new-start LRT projects, and high-floor vehicles will be used only for vehicle replacement or line extensions on systems with high-platform stations.